Nickel

Symbol: Ni

Atomic Number: 28
(protons in nucleus)

Atomic Weight: 59
(naturally occurring)

What Is It? Nickel is a hard, silvery-white metal that is malleable and ductile. It occurs in nature as five stable isotopes. (Isotopes are different forms of an element that have the same number of protons in the nucleus but a different number of neutrons.) Nickel-58 is the most prevalent form, comprising about two-thirds of natural nickel. The other four stable isotopes and their relative abundance are nickel-60 (26%), nickel-61 (1.1%), nickel-62 (3.6%), and nickel-64 (0.9%).

Of the six major radioactive isotopes, only two – nickel-59 and nickel-63 – have half-lives long enough to warrant concern. The half-lives of all other nickel isotopes are less than six days. Nickel-59 decays with a half-life of 75,000 years by electron capture, and nickel-63 decays with a half-life of 96 years by emitting a beta particle. Both isotopes are present in wastes resulting from the reprocessing of spent nuclear fuel. Nickel-63 is generally the isotope of most concern at U.S. Department of Energy (DOE) environmental management sites such as Hanford. The long half-life of nickel-59 (with its subsequent low specific activity) combined with its low decay energy limits the radioactive hazards associated with this isotope.

Radioactive Properties of Key Nickel Isotopes

Isotope	Half-Life *(yr)*	Specific Activity *(Ci/g)*	Decay Mode	Radiation Energy *(MeV)*		
				Alpha *(α)*	Beta *(β)*	Gamma *(γ)*
Ni-59	75,000	0.082	EC	-	0.0046	0.0024
Ni-63	96	60	β	-	0.017	-

EC =electron capture, Ci = curie, g = gram, and MeV = million electron volts; a dash means the entry is not applicable. (See the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients for an explanation of terms and interpretation of radiation energies.) Values are given to two significant figures.

Where Does It Come From? Nickel is naturally present in various ores and to a lesser extent in soil. It occurs in minerals such as garnierite, millerite, niccolite, pentlandite, and pyrrhotite, with the latter two being the principal ores. It is also found in most meteorites and often serves as one of the criteria for distinguishing a meteorite from other minerals. Most of the world's supply of nickel is mined in Canada; other sources include Cuba, the former Soviet Union, China, and Australia. The United States has no large deposits of nickel and accounts for less than 1% of the annual world output. Most nickel used in the United States is imported, and about 30% of the annual consumption is from recycled sources.

The two radioactive isotopes of potential concern are produced by neutron activation of components in nuclear reactors. When a fissile nuclide such as an atom of uranium-235 fissions, it generally splits asymmetrically into two large fragments – fission products with mass numbers in the range of about 90 and 140 – and two or three neutrons. (The mass number is the sum of the number of protons and neutrons in the nucleus of the atom.) These neutrons can cause additional fissions (producing a chain reaction), escape from the reactor, or irradiate nearby materials. A number of reactor components are made of various alloys of steel that contain chromium, manganese, nickel, iron, and cobalt, and these elements can absorb neutrons resulting in radioactive isotopes, including nickel-59 and nickel-63. Nickel-59 and nickel-63 are radionuclides of concern in spent nuclear fuel (as a component of the fuel hardware) and the radioactive wastes associated with operating nuclear reactors and fuel reprocessing plants. Nickel-63 is present in much higher concentrations than nickel-59.

How Is It Used? Nickel is used in various coins and as a component of several alloys, including nichrome and permalloy, and in some stainless steels. Alnico, an alloy of aluminum, nickel, cobalt, and other metals, is used to make high-strength, permanent magnets. Nickel alloy steels are used in heavy machinery, manufacturing, armaments, tools, and high-temperature equipment, including gas turbines and environmental devices used to control emissions such as scrubbers. Nickel is also used as a protective and ornamental coating for metals susceptible to corrosion, particularly iron and steel. The nickel plate is deposited by electrolysis in a nickel solution, and the coating can be highly polished.

What's in the Environment? Nickel is present in crustal rock at a concentration of about 90 milligrams per kilogram (mg/kg). Its concentration in seawater is about 2 mg per liter (mg/L). Trace amounts of nickel-59 and nickel-63 are present around the globe from radioactive fallout. It can also be present at certain nuclear facilities as a contaminant from operating reactors and processing spent fuel. Nickel is generally one of the less mobile radioactive metals in the environment. The typical ratio of the concentration of nickel in plants to that in soil is low, estimated at 0.06 (or 6%). It also adheres quite well to soil. The concentration of nickel associated with sandy soil particles is typically about 400 times higher than in interstitial water (in the pore spaces between the soil particles); it binds even more tightly to clay soil where concentration ratios can exceed 600. Thus, nickel is generally not a major contaminant in groundwater at DOE sites.

What Happens to It in the Body? Nickel can be taken into the body by eating food, drinking water, or breathing air. Children, and to a lesser extent adults, can also be exposed by ingesting soils. Gastrointestinal absorption from food or water is the principal source of internally deposited nickel in the general population. About 5% of the amount ingested is absorbed into the bloodstream through the intestines, while 20 to 35% of inhaled nicked is absorbed through the lungs. Of the nickel that reaches the blood, 68% is rapidly excreted in urine, while 2% remains in the kidneys with a very short biological half-life of 0.2 days (about 5 hours). The remaining 30% is evenly distributed to all remaining tissues of the body, including the kidneys, and clears with a biological half-life of more than 3 years (1,200 days). (This information is based on simplified models that do not reflect intermediate redistribution.) Nickel can be absorbed into the skin where it may stay, instead of being absorbed into the blood.

What Are the Primary Health Effects? Nickel is a radiogenic health hazard only if it is taken into the body. External gamma exposure is not a concern because nickel-63 and nickel-59 do not emit significant gamma radiation. Nickel-63 decays by emitting a beta particle and nickel-59 decays by electron capture, in which low-energy gamma radiation is emitted. While in the body, radioactive nickel presents a health hazard from the beta particles and gamma radiation; the main health concern is associated with the increased likelihood of inducing cancer. Nickel also exhibits chemical toxicity. The most common effect is an allergic reaction of the skin, with about 10 to 15% of the population sensitive to nickel (e.g., in jewelry). Less frequently, nickel induces asthmatic attacks. Both human and animal studies indicate that the respiratory system is the primary target following acute inhalation of high concentrations of nickel. Acute toxicity following ingestion of high concentrations includes effects on the gastrointestinal system, blood, and kidneys. Effects reported in studies of workers chronically exposed to airborne nickel dusts include chronic bronchitis, reduced lung function, and cancer of the lung and nasal sinus. The U.S. Environmental Protection Agency (EPA) has classified nickel subsulfide (a relatively insoluble form of nickel) as a known human carcinogen.

What Is the Risk? Lifetime cancer mortality risk coefficients have been calculated for nearly all radionuclides, including nickel *(see box at right).* While the coefficients for ingestion are somewhat lower than for inhalation, ingestion is generally the most common means of entry into the body. Similar to other radionuclides, the risk coefficients for tap water are about 70% of those for dietary ingestion. The EPA has developed toxicity values to estimate the risk of getting cancer or other adverse health effects associated with the chemical toxicity of nickel *(see box at right).* The toxicity value for estimating cancer risk following inhalation exposure is called a unit risk (UR), which is an estimate of the chance that a person will get cancer from continuous exposure to a chemical in air at a concentration of 1 milligram per cubic meter (mg/m^3). For example, using the inhalation UR, the EPA estimates that a person would have a one-in-a-million chance of developing cancer if exposed daily over a lifetime to air containing 0.002 microgram per cubic meter ($\mu g/m^3$) nickel subsulfide. The toxicity value for estimating non-cancer effects is a reference dose (RfD), which is an estimate of the highest dose that can be taken in every day without causing an adverse effect. The RfD for nickel was developed by studying test animals given relatively high doses over their lifetimes, then adjusting and normalizing those results to a mg per kg-day basis for humans. EPA has not derived a toxicity value for evaluating non-cancer effects of nickel following inhalation exposure.

Radiological Risk Coefficients

This table provides selected risk coefficients for inhalation and ingestion. Recommended default absorption types were used for inhalation, and dietary values were used for ingestion. Risks are for lifetime cancer mortality per unit intake (pCi), averaged over all ages and both genders (10^{-12} is a trillionth). Other values, including for morbidity, are also available.

Isotope	Lifetime Cancer Mortality Risk	
	Inhalation (pCi^{-1})	Ingestion (pCi^{-1})
Nickel-59	3.6×10^{-13}	2.3×10^{-13}
Nickel-63	1.4×10^{-12}	5.7×10^{-13}

For more information, see the companion fact sheet on Radioactive Properties, Internal Distribution, and Risk Coefficients and the accompanying Table 1.

Chemical Toxicity Values

Form of Nickel	Cancer Risk	Non-Cancer Effect
	Inhalation UR	***Oral RfD***
Soluble salts	None established	0.02 mg/kg-day
Nickel carbonyl	None established	None established
Nickel refinery dust	2.4×10^{-1} per mg/m^3	None established
Nickel subsulfide	4.8×10^{-1} per mg/m^3	None established